Abstract

Polymers are widely used as insulating materials in high voltage power apparatus because of their excellent electrical insulating properties and good thermomechanical behavior. However, under high electrical stress, polymeric materials can get deteriorated which can eventually lead to the failure of the insulation and thereby the power apparatus. Electrical treeing is one such phenomena whereby dendritic paths progressively grow from a region of high electrical stress and branch into conducting channels in a solid dielectric. The propagation of electrical trees is of particular interest for the power industry as it is one of the major causes of failure of high voltage insulation especially in high voltage cables, cast resin transformers as well as rotating machines. To improve the life time of the electrical insulation systems there is a need to improve the electrical treeing resistance of the insulating material for high voltage application. With the development of nanotechnology, polymer nanocomposites containing nano sized particles have drawn much attention as these materials are found to exhibit unique combinations of physical, mechanical and thermal properties that are advantageous as compared to the traditional polymers or their composites. Literature reveals that significant progress has been made with respect to the mechanical, optical, electronic and photonic properties of these functional materials. Some efforts have also been directed towards the study of dielectric/electrical insulation properties of these new types of materials. Considering the above facts, the present research work focuses on utilizing these new opportunities which have been opened up by the advent of nanocomposites to develop tree resistant insulating materials for high voltage power applications.

Electrical treeing is a common failure mechanism in most of the polymeric insulation systems and hence electrical treeing studies have been carried out on two types of polymers (viz. polyethylene used in high voltage cable and epoxy used in rotating machines and resin cast transformers) along with three different types of nano-fillers, viz. Al_2O_3, SiO_2 and MgO and with different filler loadings (0.1, 1, 3, 5 wt%). Furthermore, considering the fact that electrical treeing is a discharge phenomenon, the partial discharge characteristics during electrical tree growth in polymer nanocomposites was studied. As morphological changes in the polymer influence the electrical tree growth, the influence of nano-particle induced morphological changes on the electrical treeing has also been studied. Above all, an attempt has also been made to characterize and analyze the interaction dynamics at the interface regions in the polymer nanocomposite and the influence of these interface regions on the tree growth phenomena in polymer nanocomposites.

A laboratory based nanocomposite processing method has been successfully designed and adopted to prepare the samples for treeing studies. Treeing experimental results show that there is a significant improvement in tree initiation time as well as tree inception voltage with nano-filler loading in polymer nanocomposites. It is observed that even with the addition of a small amount (0.1 and 1 % by weight) of nano-particles to epoxy results in the improvement of electrical treeing resistance as compared to the unfilled epoxy. In fact, different tree growth patterns were observed for the unfilled epoxy and epoxy nanocomposites. Surprisingly, even though there is not much improvement in tree inception time, a saturation tendency in tree growth with time was observed at higher filler loadings. To understand the influence of nano-particles on electrical treeing, the interaction dynamics in the epoxy nanocomposites were studied and it was shown that the nature of the bonding at the interface play an important role on the electrical tree growth in epoxy nanocomposites. The results of electrical treeing experiments in polyethylene nanocomposites obtained in this study also reveal some interesting findings. An improved performance of polyethylene against electrical treeing with the inclusion of nano-fillers is observed. It is observed that there is a significant improvement in the tree inception voltage even with low nano-filler loadings in polyethylene. Other interesting results such as change in tree growth pattern from branch to bush as well as slower tree growth with increase in filler loading were also observed. Another peculiar observation is that tree inception voltage increased with increase in filler loading upto a certain filler loadings (3 % by weight) and then decreased in its value at high filler loading. The morphology of polyethylene nanocomposites was studied and a good correlation between morphological changes and treeing results was observed. Effect of cross-linking on electrical treeing has also been studied and a better performance of cross-linking of nano-filled polyethylene samples as compared to the polyethylene samples without cross-linking was observed.

The partial discharge (PD) activity during electrical tree growth was monitored and different PD characteristics for unfilled and nano-filled polyethylene samples were observed. Interestingly, a decrease in PD magnitude as well as the number of PD pulses with electrical tree growth in polyethylene nanocomposites was observed. It is known that PD activity depends on the tree channel conductivity, charge trapping and gas pressure inside the tree channel. The ingress of nano-particles into the tree channel influences the above known phenomena and affects the PD activity during electrical tree growth. The observed decrease in PD magnitude with increase in filler loading leads to the slow propagation of electrical trees in polyethylene nanocomposites.

In summary, it can be concluded that polymer nanocomposites performed better against electrical treeing as compared to the unfilled and the conventional micron sized filled polymer composites. Even with low filler loading an improved electrical treeing resistance was observed in polymer nanocomposites. An optimum filler loading and a suitable filler to inhibit electrical treeing in the polymers studied are proposed. This work also establishes the fact that the characteristics of the interface region and the induced morphological changes have a strong influence on the electrical treeing behaviors of nanocomposites. These encouraging results showed that epoxy and polyethylene nanocomposites can be used as tree resistant insulating materials for high voltage applications. These results also contribute to widen the scope of applications of polymer nanocomposites in electrical power sector as well as development of multifunctional insulation systems.